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Track Recognition Using Two-Dimensional Symbols or Three-Dimensional Realistic Icons

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ADMINISTRATIVE INFORMATION

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EXECUTIVE SUMMARY

Conventional tactical displays use nonrealistic two-dimensional (2-D) symbols to depict military assets. Prototypes of three-dimensional (3-D) tactical displays are being developed that depict assets using miniature realistic icons, mostly of ships and planes. Our objective was to test the performance benefits of these icons.

In four experiments, we presented participants 10 common military platforms displayed as 3-D icons, 2-D icons, or conventional 2-D symbols (Military Standard 2525). We found that:

• Symbols were identified faster than icons.

• Symbols were identified more accurately than icons.

• Symbols were identified better than icons even when the participants were experts.

• Platform identification can be improved when the symbol includes the first letter of the platform unless more than one platform displays the same first letter.

• 3-D icon identification accuracy varies with heading; this is not true for 2-D symbols.

• 3-D icons are confused more often with platforms of the same category.

• 2-D icons and 3-D icons were equally effective for platform identification.

• 2-D symbols and 3-D icons were equally effective for categorization into general classes of platforms (e.g., ships, aircraft).

Our results suggest that realistic icon recognition is poor because it is difficult for users to discriminate among the subtle visual differences of military platforms. In contrast, military symbols have been engineered as distinctive for similar-looking real-world objects. Users may want a familiar realistic representation of military platforms on their display, but they perform better with a distinctive and, sometimes unrealistic, depiction. We recommend using 2-D symbols over 3-D icons. If the display configuration requires icons, adding the first letter of the platform name to the icon will make rapid and accurate identification easier.

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INTRODUCTION

Three-dimensional (3-D) perspective displays of air spaces and military maps are now designed with realistically drawn 3-D icons instead of conventional military or civilian symbols. The Area Air Defense Commander (AADC) 3-D display prototype (figure 1) uses 3-D icons (Dennehy, Nesbitt, and Sumey, 1994). Do 3-D icons translate into performance benefits for the users of these displays? We have found surprisingly limited research on this question. The use of 3-D icons must be evaluated now if we are to influence the design of new operational displays.

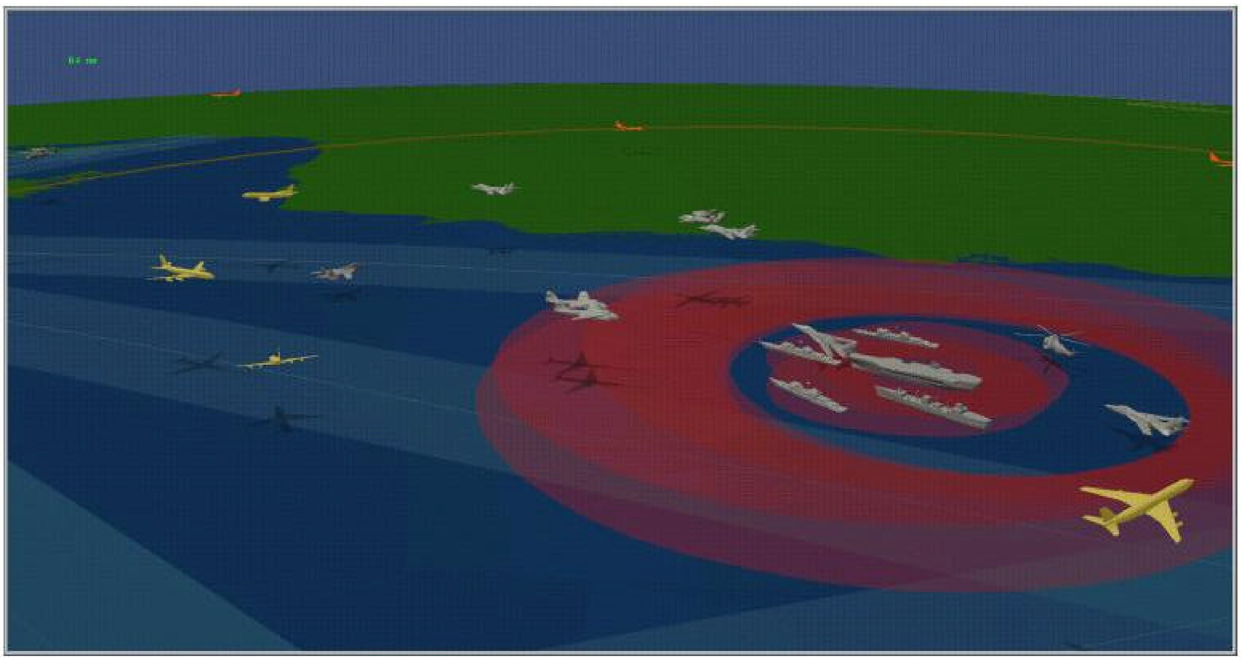

Figure 1. 3-D display populated with realistic 3-D icons. The screenshot is from an early version of the AADC display prototype (from Smallman, Schiller, and Mitchell, 1999).

We can divide the performance of 3-D perspective displays (e.g., figure 1) into two issues. The first issue is how the positioning of the objects and the rendering of 3-D space and terrain layout affect performance. The second issue is how the representation of objects as realistic 3-D icons or conventional military 2-D symbols affects performance. This report investigates the second issue.

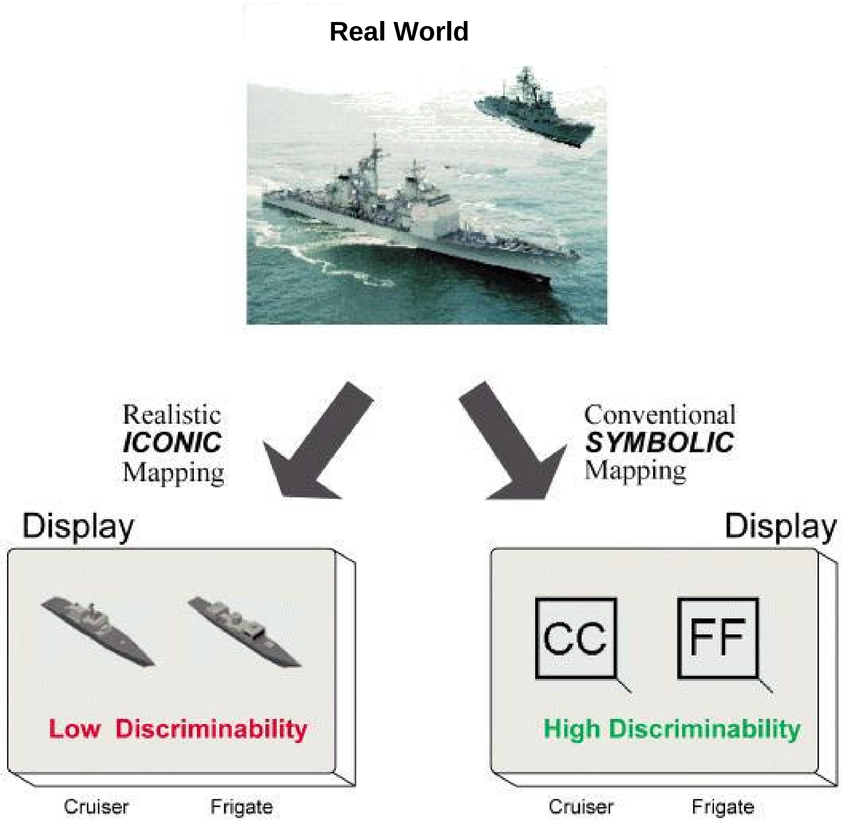

Figure 2. Two ways of mapping objects in the world on a display. Left, objects are mapped realistically as 3-D icons. Right, objects are mapped as 2-D symbols (Military Standard 2525). The mapping on the right gives higher discrimination between the cruiser and frigate.

Figure 2 shows two ways of mapping real-world objects on a display as symbols. Symbols represent something else because of a relationship or association. If that relationship is pictorial, then we define those symbols as icons. Figure 2 shows 3-D icons of two ships, a cruiser and a frigate. The 3-D icons are as realistic as possible and are popular with users. The right of figure 2 shows a conventional 2-D symbolic mapping of the same two ships (from the Military Standard 2525 symbol set). Note that the first letter of each ship's platform name is part of the symbol.

Besides identification, military symbols must also encode and convey other attributes of the represented platforms. For example, the ship heading is encoded on the conventional 2-D symbols by a black line (called a leader) emanating from the symbol in the appropriate direction (southeast in this case). The heading is encoded on the 3-D icons by the orientation of the icons on the display.

How does the choice of a conventional 2-D symbol or a realistic 3-D icon impact user performance? Performance will depend on several important factors: (1) the nature of the mapping from objects to symbols, (2) familiarity and training, and (3) discriminability (Christ and Corso, 1983; Geiselman, Landee, and Christen, 1982).

Previous research suggests that 3-D icons would benefit perceptual search and identification of objects because the iconic mapping from objects to their physical shapes is direct and intuitive. For example, pictures of familiar objects are named faster than pictures of unfamiliar ones (Oldfield and Wingfield, 1965). In contrast, the mapping among platforms and their military symbols is more abstract. Even for military personnel, familiarity with the military symbol mapping should lag behind familiarity with physical shape mapping. Not all symbol mappings in the military are arbitrary. Some symbol mappings are governed by real-world metaphors of the platforms (e.g., a bow tie to represent the rotor blades of a helicopter).

While the general population knows the physical mapping and can discriminate easily between general categories such as between ships and aircraft, or even between fighters and airliners, they might not be able to discriminate between specific category members. For example, to discriminate the cruiser from the frigate on the left of figure 2, you must learn the fine differences in their superstructure, and such knowledge requires training just as the mappings between objects and military symbols requires training. One advantage of military symbols over icons is that symbols can be created with high discrimination, such as the symbols for the two ships on the right of figure 2.

How do these considerations affect the use of 3-D icons and 2-D symbols on tactical displays? We should design symbol sets that allow users to quickly extract the identity and other attributes of objects. We need answers to several questions. Are 3-D icons classified into general categories more accurately than 2-D symbols? Are realistically drawn 3-D icons identified faster than conventional military 2-D symbols? Are the attributes of the objects such as altitude, attitude, and heading of aircraft understood faster with 3-D icons than 2-D symbols?

Florence and Geiselman (1986) compared performance with 2-D realistic icons and 2-D symbols for the time required to find objects on a map. Their 2-D icons were simple line drawings of military objects such as tanks, infantry, and helicopters. Their 2-D symbols were from a conventional military symbol set. Florence and Geiselman found that the icons had a small advantage in cluttered displays in which participants were given a name rather than a picture of what to search for. However, they only gave their participants 1 minute to learn the mapping from names to the symbols, and their symbols were not discriminable. With more training, perhaps performance with the symbols would have improved and the small icon advantage would have disappeared. The pictorial nature of icons might also allow them to be classified faster into general categories such as ships and aircraft. Snodgrass and McCullough (1986) have shown that visually similar pictorial items may be classified into general categories faster than they can be identified.

However, a North Atlantic Treaty Organization working group (NATO, 1989) found a different result pattern when they evaluated competing symbologies for the NATO maritime set (a pre-cursor to Military Standard 2525). In a visual search and simple recall task, they found 2-D symbols that used the first letters of names (such as F for fighter) superior to a mix of simple 2-D icons and analogous symbols (such as a bow tie to represent the rotor blades of a helicopter).

Beyond identification, users may extract certain object attributes better from 3-D icons than 2-D symbols. Baumann, Blanksteen, and Dennehy (1997) created high-resolution 3-D models of aircraft and found that participants could perceive the attitude of the aircraft (nose up or down) directly from their icons—information that conventional 2-D military symbols do not directly display. Smallman, Schiller, and Mitchell (1999) found that in addition to attitude, participants are more aware of the attributes of altitude and heading with realistic 3-D icons compared to military 2-D symbols. Such direct perception of important information would make 3-D icons a valuable alternative to conventional 2-D symbols. However, pictures of objects are not equally recognizable from all viewing angles. For example, a plane seen from head-on is more difficult to recognize than when seen from the side (e.g., Jolicouer and Humphrey, 1998).

Several theoretical models of visual object recognition predict that the realism of icons should lead to faster identification (Marr and Nishihara, 1978; Biederman, 1987). Supporting this idea, Liter, Tjan, Bulthoff, and Kohnen (1997) measured naming latencies for shaded objects versus the outlines of those objects. They controlled for visual complexity and found a marginal advantage for the shaded objects. However, in a similar study, Hayward (1998) found a marginal advantage for outlines.

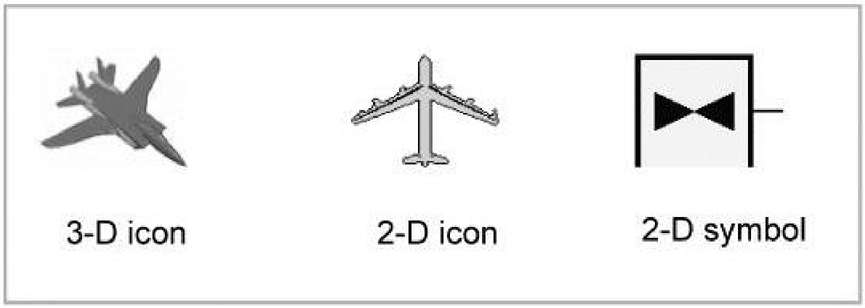

Figure 3. Three different types of military icons or symbols that were to be identified in the experiments: Left, 3-D icon of a fighter; center, a 2-D icon of a bomber; and right, a 2-D symbol of a helicopter.

OBJECTIVE

Our objective was to find out if there are performance advantages for 3-D icons. In four experiments, we asked participants to identify common military platforms displayed as 3-D icons, 2-D icons, or conventional 2-D symbols. The 2-D icon condition was added to our study of 3-D icons versus symbols to separate the effects of three-dimensionality from the pictorial nature of 3-D icons. Figure 3 shows examples of the icons and symbols.

EXPERIMENT 1

In Experiment 1, we tested the hypothesis that realistically drawn 3-D icons are correctly identified faster than conventional military 2-D symbols. We measured the time required for participants to provide the platform name of the symbol or icon and compared these latencies across the following conditions: 3-D icons, 2-D icons, or 2-D symbols.

We controlled for familiarity with military symbols by using non-military participants, though perhaps there might be a general predisposition for the shapes of ships and aircraft. We chose 10 military platforms that would be commonly seen on a tactical display. We presented the icons and symbols at five different headings.

METHOD

Participants

Twelve students from two local colleges were paid for their participation. Their average age was 23.6 years.

Materials

The stimuli were 10 military platforms drawn as 3-D icons, 2-D icons, or conventional military 2-D symbols (figure 4). Stimuli included five surface/subsurface platforms (carrier, cruiser, frigate, submarine, and tanker) and five air platforms (bomber, civilian, fighter, helicopter, and missile). We used the Military Standard 2525 symbol set for our 2-D symbols. This set is new and not yet widely used, though it is similar to current NATO maritime symbology. Military Standard 2525 is useful because it differentiates symbols at the platform (e.g., fighters, bombers, cruisers), but the commonly used Naval Tactical Data System (NTDS) symbol set only shows the category of each platform (i.e., air, surface, and subsurface). This feature allows us to directly compare participant performance between icons and symbols for the same platforms.

The 3-D icons were created from computer models of the 10 platforms. The camera was elevated 45 degrees above the horizontal plane and far enough away from the model so that the icon filled a 1.5-inch by 1.5-inch square on the screen. A 45-degree elevation is a common viewing angle for 3-D perspective displays (Dennehy, Nesbitt, and Sumey, 1994; Wickens, Todd, and Seidler, 1989). The icons subtended 4.7 x 4.7 degrees of visual angle at the viewing distance used here (where 1 degree of visual angle is approximately the angle your thumb subtends at arm's length). The models were illuminated with an omnidirectional, distant light source directly above the models. Appropriate shading was added by coloring the surface of the model body dark gray (50% gray) and the model features light gray (25% gray). Images were rendered using the RDI Ray Tracer with the reflection setting turned off. Each model was rendered at five headings (north, northeast, east, southeast, and south) by rotating the model in the horizontal plane. We did not test the comparable westward headings because they are symmetrical on the horizontal plane to the eastward headings. We imaged the aircraft in steady flight (not ascending or descending). We equated the pixel count across orientations within a platform so that comparably sized views were available for each depicted heading.

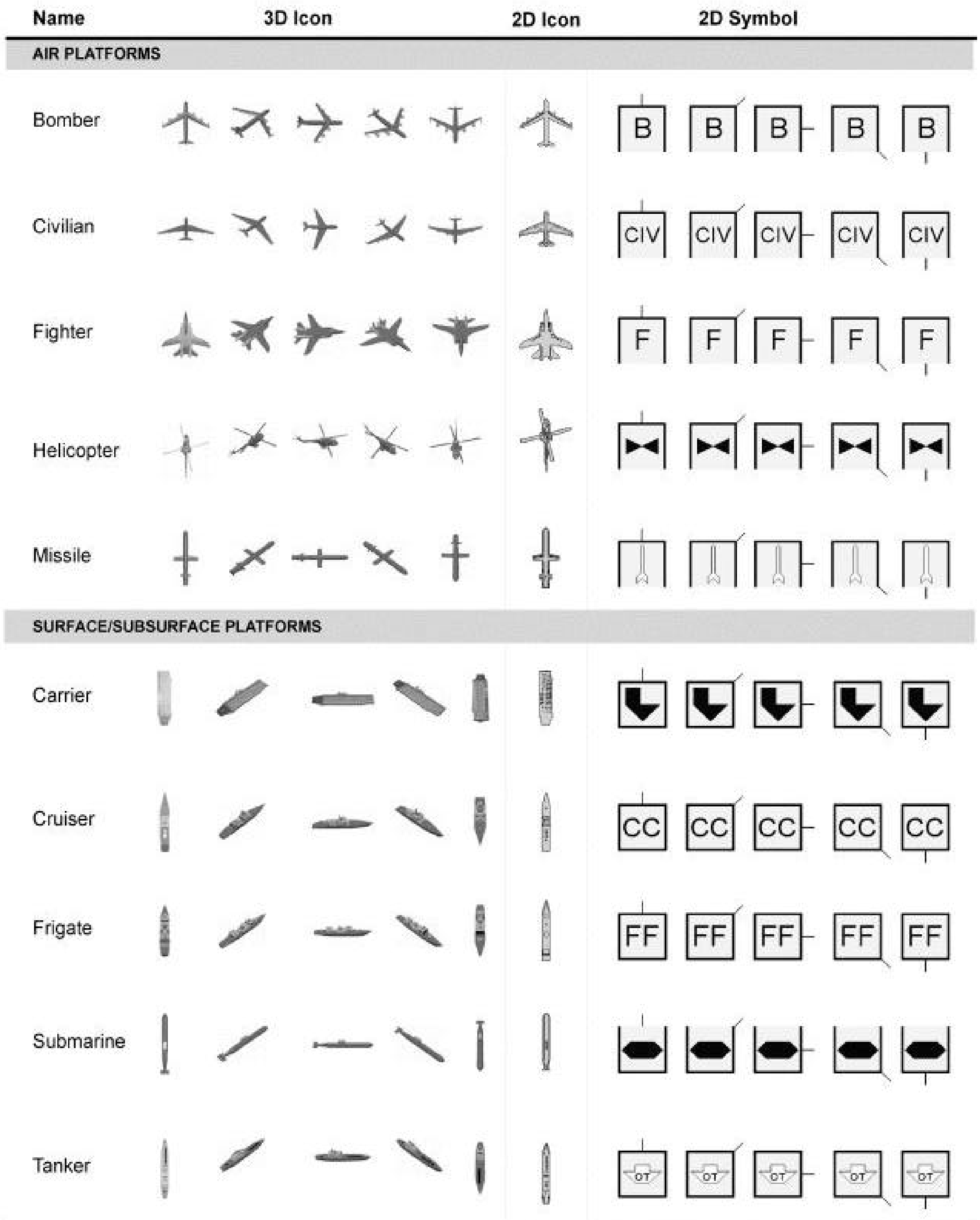

Figure 4. The 3-D icons, 2-D icons, and 2-D symbols (Military Standard 2525) used as stimuli in Experiments 1 and 2. The icons and symbols for the civilian airliner and the frigate were excluded from Experiment 2. The stimuli shown here are smaller than those used in the experiments.

The 2-D icons were created the same way as the 3-D icons except the camera was elevated 90 degrees above the horizontal plane looking straight down. All shading information was removed from the rendered images and replaced with 15% gray. Important features of each 2-D icon were then added and drawn in black to roughly equate the visual complexity of the 2-D and 3-D icons. The 2-D icons were only drawn with a **north** heading because the 2-D icons were visually similar (figure 4) to the 3-D icons. We needed to roughly equate the number icons and symbol trials to prevent more training on icons than symbols.

The 2-D symbols were drawn to match the length and width of the 3-D and 2-D icons. The 2-D symbols were shaded a uniform 7% gray. The 2-D symbols were drawn with the same five headings as the 3-D icons. The heading was displayed as a short line (called a heading leader) extending from the symbol in the appropriate direction.

Across conditions, we roughly equated the contrast and size of the stimuli so that differences in latencies would not show differences in the visibility of the stimuli (Harwerth and Levi, 1978). Stimuli were shown on a 14-inch color monitor.

Procedure

Participants were first introduced to the symbols and icons by studying a poster showing the different sets (figure 4) for 5 minutes. Participants were seated approximately 18 inches from the computer monitor. Each trial began with a short, blank interval followed by the presentation of a stimulus (3-D icon, 2-D icon, or 2-D symbol) at the center of the display. Participants were instructed to name the displayed stimulus with a single word as quickly as possible and to speak their responses into a microphone directly in front of them. On every trial, feedback displaying the correct name was displayed beneath the stimulus 300 ms after a verbal response was detected. Participants then pressed a key to continue to the next trial. A tape recorder recorded the participants' verbal responses so errors could be coded later. The computer recorded verbal response latencies to an accuracy of about 1 ms.

Each participant served in four blocks of 110 trials each. Fifty trials in each block presented 3-D icons (10 platforms with five headings), 50 trials presented 2-D symbols (10 platforms with five headings), and 10 trials presented 2-D icons (10 platforms with north headings). Trials were presented randomly within a block. All four blocks took about 20 minutes to finish, with the participants taking a short break between each block.

RESULTS

Naming Latencies and Accuracy

Figure 4 shows mean naming latencies (for the correct trials) and accuracy that depend on symbol type and block. Latencies on 2-D symbol trials were faster (by 294 ms), $F\ (1,11) = 69.8$, $p < .0001$, and more accurate (94.7% versus 84.3%), $F\ (1,11) = 29.1$, $p < .001$, than on 3-D icon trials. Responses were faster, $F\ (3,33) = 18.1$, $p < .0001$, and more accurate, $F\ (3,33) = 16.4$, $p < .0001$, in later blocks. Thus, participants were not engaged in some simple speed-accuracy trade-off when they named the symbols. Contrary to the hypothesis that 3-D icons would be more effective, participants were slower and less accurate in identifying 3-D icons than comparable 2-D symbols.

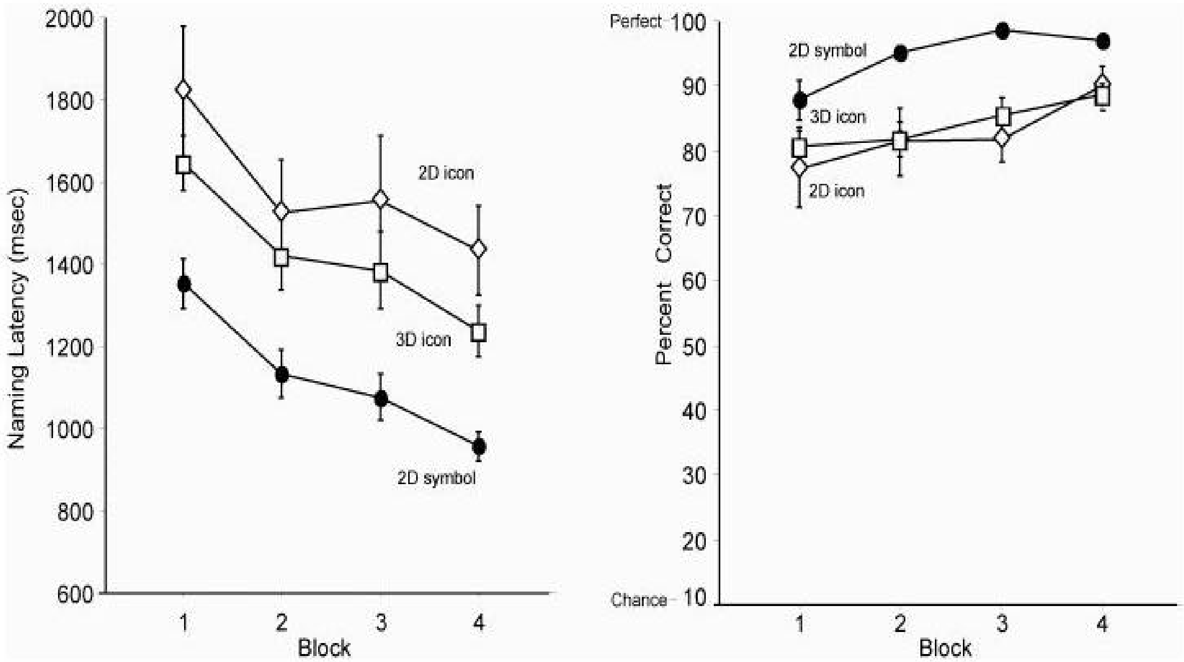

Figure 5. Mean latencies (correct trials only) and accuracy (in percent correct) scores by condition and block for Experiment 1.

There was an interaction between heading and symbol type for the latencies (F (4,44) = 2.7, $p < .05$). Separate analyses for the two symbol types revealed that performance differed significantly by heading for the 3-D icons only (F (4,44) = 2.97, $p < .01$). There was no systematic variation with heading around the clock. The three-quarter views of the icons (SE or NE) were not faster than the other headings. The 3-D icons with east (1350ms) or northeast (1355 ms) headings were identified the fastest, followed by north (1422 ms), southeast (1495 ms), and south headings (1501 ms). Thus, by coding heading realistically with 3-D icons, the icons become slightly less identifiable at certain headings.

North Headings

To analyze data for the 2-D icons, which only have northern headings, the naming latencies and accuracy for north headings of all three symbol types were analyzed in a two-way repeated measure analysis of variance (ANOVA). This analysis showed that 2-D symbols were named faster than 2-D icons (by 475 ms) and 3-D icons (by 303 ms), F (2,22) = 16.54, $p < .0001$. Two-dimensional symbols were named more accurately than 2-D icons (by 12.1%) and 3-D icons (by 10.6%), F (2,22) = 14.58, $p < .01$. There were no significant differences between the 2-D icons and 3-D icons. Thus, icons were slower than symbols, and it did not matter whether the icons were depicted in 2-D or 3-D.

What could have accounted for such a staggering advantage in identifying the 2-D symbols over the 2-D and 3-D icons? An obvious first step was to look at the data by individual platform to see if any consistent pattern emerged in the type of symbols that produced the best performance. Figure 6 shows this breakdown for the final block of trials.

An important factor was whether a symbol included the first letter of the platform's name. In figure 6, the platforms are grouped into those whose 2-D symbol included the first letter from their name ('B' for bomber, 'F' for fighter, 'CC' for cruiser, 'CIV' for civilian, 'FF' for frigate, and 'OT' for oiler tanker) and those whose 2-D symbol is some other graphical or analogical relationship. The platforms whose 2-D symbols included first letters were named <u>380 ms faster</u> (30% on average) than the 3-D icons (figure 6, left side), which was statistically significant $F(1,11) = 36.57$, $p < .0001$. Platforms whose 2-D symbols did not include first letters (figure 6, right side) were named 120 ms faster than the 3-D icons, which was statistically significant, $F(1,11) = 7.3$, $p < .05$.

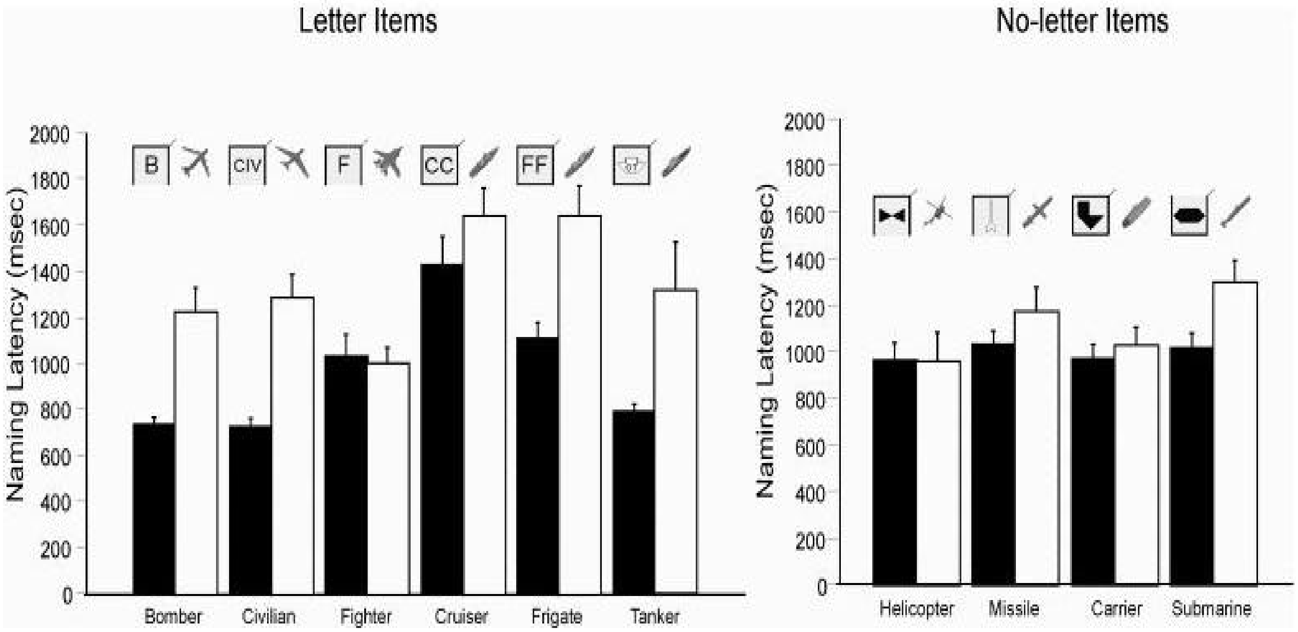

Figure 6. What made the 2-D symbols easy to identify? Shown are mean latencies (correct trials only) for symbols and icons of individual platforms from the last block broken down by whether the symbols included the first letter of the platform to be named.

Figure 7 shows this letter/no-letter breakdown across block (figure 5). Figure 7 shows just how much faster 2-D symbols were named when they included first letters. A 3-way ANOVA confirmed a main effect of including versus not including first letters, F (1,11) = 16.4, p < .01.

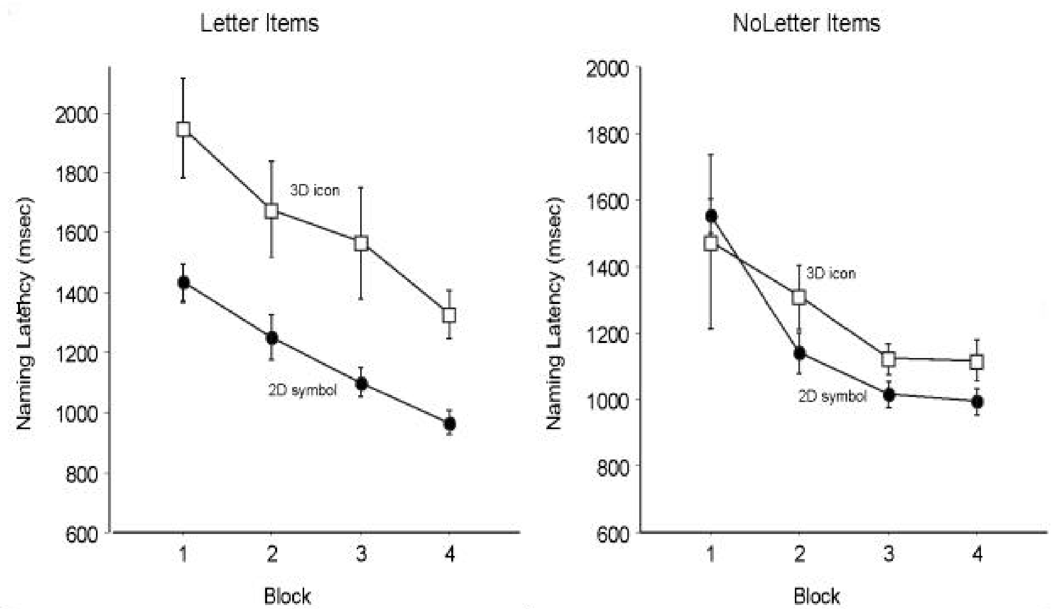

Figure 7. Mean latencies (correct trials only) in Experiment 1, by block, for symbols and icons whose 2-D symbols included letters (left panel) or no letters (right panel).

After the first block, “no-letter” 2-D symbols were named faster than the 3-D icons. This fact suggests that inclusion of a first letter was not the only reason that 2-D symbols were named faster. To find out what might explain the advantage of the 2-D symbols, we analyzed participant confusions that led to incorrect responses.

Confusions

A confusion occurred when a participant supplied the wrong platform name for the symbol or icon. When participants made confusions, what was the mistake? Figure 8 shows a matrix of the confusions for the 2-D symbols and for the 3-D icons.

The overall confusion rate in the experiment was 9.4%. It was 4.5% for the 2-D symbols and 14.3% for the 3-D icons. Certain confusions were common. The 2-D symbols for air platforms were never confused with each other, but the civilian aircraft was consistently confused with the bomber in the 3-D icon set

For surface platforms, frigates were consistently confused with cruisers when shown in iconic form, but frigates were confused with fighters in the 2-D symbolic form (‘FF’ versus ‘F’). A systematic pattern in the confusions emerged when we categorized the confusions as (1) those where platforms were confused with platforms from the same platform category (e.g., surface for surface, and air for air), and (2) those where platforms were confused with other platforms sharing the same first letter (e.g., 'Frigate' for ‘Fighter’). Table 1 shows the percentage of confusions made in these two categories.

2-D Symbols

Participant's Response

Correct Response		Bomber	Civilian	Fighter	Helicopter	Missile	Carrier	Cruiser	Frigate	Submarine	Tanker
		Air					Sea				
Air	Bomber										
	Civilian										
	Fighter								25		
	Helicopter										
	Missile									8	
Sea	Carrier	1						1			
	Cruiser	1	9				18				
	Frigate	1	1	14							
	Submarine				4	1		2	1		
	Tanker										

3-D Icons

Participant's Response

Correct Response		Bomber	Civilian	Fighter	Helicopter	Missile	Carrier	Cruiser	Frigate	Submarine	Tanker
		Air					Sea				
Air	Bomber		21	2							
	Civilian	29		1		1					
	Fighter						1				
	Helicopter										
	Missile									11	
Sea	Carrier							5			
	Cruiser	1	1	1			7		76		9
	Frigate		2				5	87		2	12
	Submarine					24					
	Tanker							27		1	

N confusions	0-10	11-20	21-50	51+

Figure 8. What platforms did participants confuse in Experiment 1? Top panel shows the confusion matrix for the 2-D symbols. Columns show participant responses and rows show the correct responses. The bottom panel shows the same information for the 3-D icons. Numbers indicate total confusions. These are coded with increasing numbers shaded darker.

Table 1. Number of confusions (Experiment 1) by condition for confusions that were made within a platform category and for confusions that were made with platforms sharing the same first letter.

Condition	Confusion Type			
	Platform Category	Not Platform Category	First Letter	Not First Letter
2-D Symbol	(44) 40%	(59) 60%	(76) 70%	(76) 30%
3-D Icon	(303) 88%	(41) 12%	(13) 4%	(331) 96%

3-D icons were mistaken for other icons that looked similar, and 2-D symbols were mistaken for other symbols including the same first letter. Table 1[1] shows that 88% of the confusions for the 3-D icons were for another platform in the same category. Air platforms were predominantly confused with other air platforms, and surface platforms were confused with other surface platforms ($\chi^2 = 147.5$, $df = 1$, $p < .001$). The only notable exception to this pattern was that the missile was readily mistaken for the submarine and vice versa. A close look at these icons shows that the submarine and the missile were visually similar. Only 4% of the confusions with the 3-D icons were for platforms sharing the same first letter.

Two-dimensional symbols produced an opposite result pattern. Seventy percent of the confusions for 2-D symbols were for platforms including the same first letter while 40% of confusions involved errors in the same platform category. Confirming this trend, we found this difference statistically significant for confusion type ($\chi^2 = 17.7$, $df = 1$, $p < .001$).

DISCUSSION

Participants correctly identified platforms substantially quicker with 2-D symbols compared to 2-D icons or 3-D icons. Performance with the 3-D icons varied with platform heading and produced more confusion errors than the 2-D symbols. Participants confused 3-D icons with other icons from the same platform category. Icons are visually similar to the platforms and, therefore, are easily confused with similar platforms.

A post hoc comparison of performance on specific platforms showed that one key to the 2-D symbols' success was displaying the first letter of the platform's name. This design characteristic produced a 380 ms (or 30%) naming superiority for 2-D symbols over 3-D icons. However, symbols were named 120 ms faster than their 3-D icon counterparts even when the symbols did not use first letters. In practical terms, this 10 to 30% identification advantage would benefit the war fighter's ability to make the best tactical decisions.

Providing the first letter of a word will prime the naming of that word (e.g., Ferrand, Segui, and Grainger, 1996; Schiller, 1998). This characteristic is beneficial for 2-D symbols. However, it is unclear whether the first letter makes it easier for the participant to identify the platform or only name the word. It would be useful to develop a nonverbal form of the identification task, which is an experiment that we plan to conduct.

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[1] Yates' (1934) correction for continuity for a small 2 x 2 data table was used in the χ^2 test.

We have no ready explanation for the finding that 3-D icons were named fastest for eastern headings. Others have found that identification latencies for most commonly encountered objects (such as household objects and animals) are fastest for “three-quarter views,” which would equate to our southeast or northeast headings here (Liter et al., 1997; Palmer, Rosch, and Chase, 1981). The 2-D symbols were named equally fast for all headings because only the direction of the heading leader was changed and not the symbol orientation.

How do the latencies for our icons compare to others in the literature? By the end of the fourth block, latencies were about 1 second. This is comparable to latencies for naming comparably depicted 2-D pictures and 3-D shaded renderings of common objects and animals (e.g., Liter et al., 1997).

EXPERIMENT 2

The symbols and icons used in Experiment 1 had several items that participants easily confused. This situation made the experiment valid for what a military user might encounter in a tactical console, but led to a confounded measure of the identifiability of 3-D icons and 2-D symbols. In Experiment 2, we sought to replicate the results of the first experiment while refining the stimuli to eliminate the most serious confusions. Removing these confusions might provide better chance of finding a performance benefit for 3-D icons.

METHOD

Participants

Twelve students (who did not participate in Experiment 1) participated in Experiment 2. The students were from two local colleges and were paid for their participation. Their average age was 21.7 years.

Materials and Procedure

The materials and procedure were the same as in Experiment 1 with the following exceptions. We eliminated the civilian airliner because it was visually similar the bomber, and its 2-D symbol was similar to the cruiser (CIV for civilian and CC for cruiser). We also eliminated the frigate because it was visually similar to the cruiser and because its 2-D symbol was similar to the fighter (FF for frigate and F for fighter). The less visually confusing pair, missile and submarine, was retained. The resulting materials had four air platforms and four surface/subsurface platforms.

As in Experiment 1, participants viewed four blocks of trials containing all symbol types presented randomly. Again, to guard participants excessive exposure to icons, we restricted the 2-D icons to only those with north headings. Each block had 88 trials: 40 trials presented 3-D icons (eight platforms with five headings), 40 trials presented 2-D symbols (eight platforms with five headings), and eight trials presented 2-D icons (eight platforms with one heading).

RESULTS

Naming Latencies and Accuracy

Figure 9 shows mean naming latencies (for the correct trials) and accuracy as a function of symbol type and block. Responses on 2-D symbol trials were faster (by 243 ms), $F\ (1,11) = 16.6$, $p < .001$, and more accurate (94.7% vs. 87.6%), $F\ (1,11) = 12.13$ $p < .01$, than on 3-D icon trials. For all conditions, responses were faster, $F\ (3,33) = 18.8$, $p < .0001$, and more accurate, $F\ (3,33) = 28.1$, $p < .0001$, in later blocks. Over all blocks and conditions, the removal of confusable items resulted in naming latencies 130 ms faster in Experiment 2 than Experiment 1.

The interaction between symbol type and orientation for latencies was not statistically significant in the second experiment. Accuracy and naming latencies for the 2-D icon trials and 3-D icon trials was equal when items with north headings were analyzed.

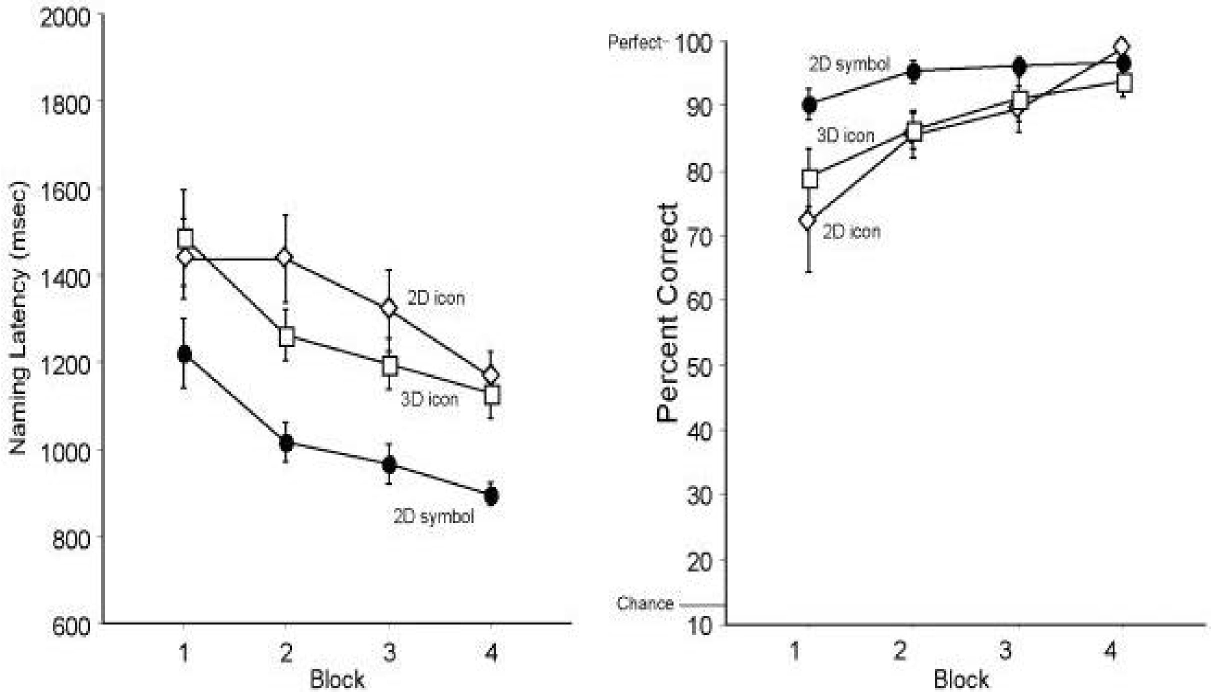

Figure 9. Mean latencies (correct trials only) and accuracy (in percent correct) scores by condition and block for Experiment 2.

Letter versus No-letter Items

As in Experiment 1, we analyzed performance by item for the fourth block of trials to see if including the first letter influenced performance (figure 10). When 2-D symbols included a first letter, they were identified 407 ms faster than the 3-D icons, F (1,11) =17.25, $p < .001$. When 2-D symbols did not include a first letter, they were identified 84 ms faster than the 3-D icons, and this difference was not statistically significant.

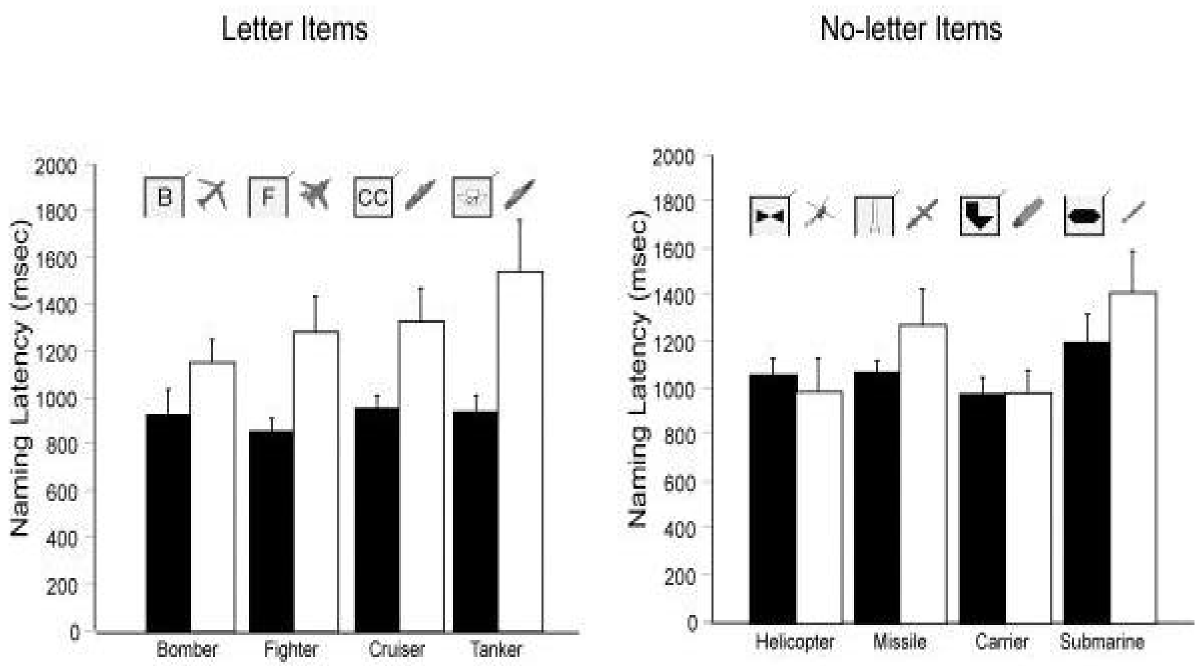

Figure 10. Mean latencies (correct trials only) for symbols and icons of individual platforms from the last block broken down by whether the symbols included the first letter of the platform to be named.

Confusions

We analyzed the pattern of confusions made with the 2-D symbols and 3-D icons as we did in Experiment 1. The confusion rate was 8.1%, 1.5% lower than in the first experiment. Broken down by condition, the confusion rates were 5.0% with 2-D symbols and 11.2% with 3-D icons. We classified the confusions into those sharing the same platform category and those sharing the same first letter. Table 2 shows this analysis[2]. Similar to Experiment 1, 2-D symbols were mistaken for those sharing the same first letter 60% of the time. This was significantly more often than the 8% first letter confusion rate for the 3-D icons (χ^2 = 28.9, *df* = 1, *p* < .001). Although most of the errors made with 3-D icons were for members of the same platform category (72%), this rate was not significantly different than that for 2-D symbols.

[2] Yates' (1934) correction for continuity for a small 2 x 2 data table was used in the χ^2 test.

Table 2. Number of confusions (Experiment 2) by condition for confusions that were made within a platform category and for confusions that were made with platforms sharing the same first letter.

Condition	Confusion Type			
	Platform Category	Not Platform Category	First Letter	Not First Letter
2-D Symbol	(73) 76%	(23) 24%	(58) 60%	(38) 40%
3-D Icon	(155) 72%	(60) 26%	(17) 8%	(198) 92%

DISCUSSION

In Experiment 2, we replicated the surprising result of Experiment 1 that performance for identifying 2-D (Military Standard 2525) symbols is dramatically better than that for 2-D icons and 3-D icons. By removing conspicuously confusable symbols from the mix of those to be identified, mean identification latencies were 130 ms faster than in Experiment 1, and accuracy improved just slightly. Nonetheless, the same pattern of 2-D symbol superiority remained. Contrary to our hypothesis, participants were slower and less accurate in identifying icons than symbols.

EXPERIMENT 3

In Experiment 3, we administered Experiment 1 to five navy experts. We reasoned that the experts would be more knowledgeable about the physical shapes of military ships and aircraft and better attuned to the subtle visual differences between them. The Military Standard 2525 symbols, while not unknown, are not commonly used by the U.S. Navy. Therefore, the experts, unlike novices from the general population, might perform better with the 3-D icons than the 2-D symbols. They might be less susceptible than the novices to confusions between similar icons.

METHOD

Participants

The participants were five individuals with an average of 13 years of naval experience who were not familiar with the Military Standard 2525 symbols. They all had substantial training and experience in visually identifying military platforms. The average age of the experts was 44.6 years, and they were paid for their participation.

Materials, Procedure, and Design

These were the same as used in Experiment 1.

RESULTS

Naming Latencies and Accuracy

Figure 10 shows mean naming latencies (for the correct trials) and accuracy as a function of symbol type and block. No effects were found for accuracy because all the experts performed close to 100%. Experts were 98.4% correct on the 2-D symbols and 94.8% correct on the 3-D icons, averaged across block. Analyses of the latencies, however, showed a similar pattern of results to that of the novices in the first two experiments. A main effect of block, $F\ (3,12) = 4.2$, $p < .05$, indicated that responses became faster with time and practice. There was also a main effect of symbol type, $F\ (1,4) = 48.3$ $p < .01$. On average, 2-D symbols were named 150 ms faster than the 3-D icons. There was also an interaction between block and symbol type, $F\ (3,12) = 4.1$, $p < .05$. There was a stronger increase in performance (shorter latencies) for the 3-D icons across the four blocks (326 ms) than for the 2-D symbols (167 ms). There was no significant effect for heading.

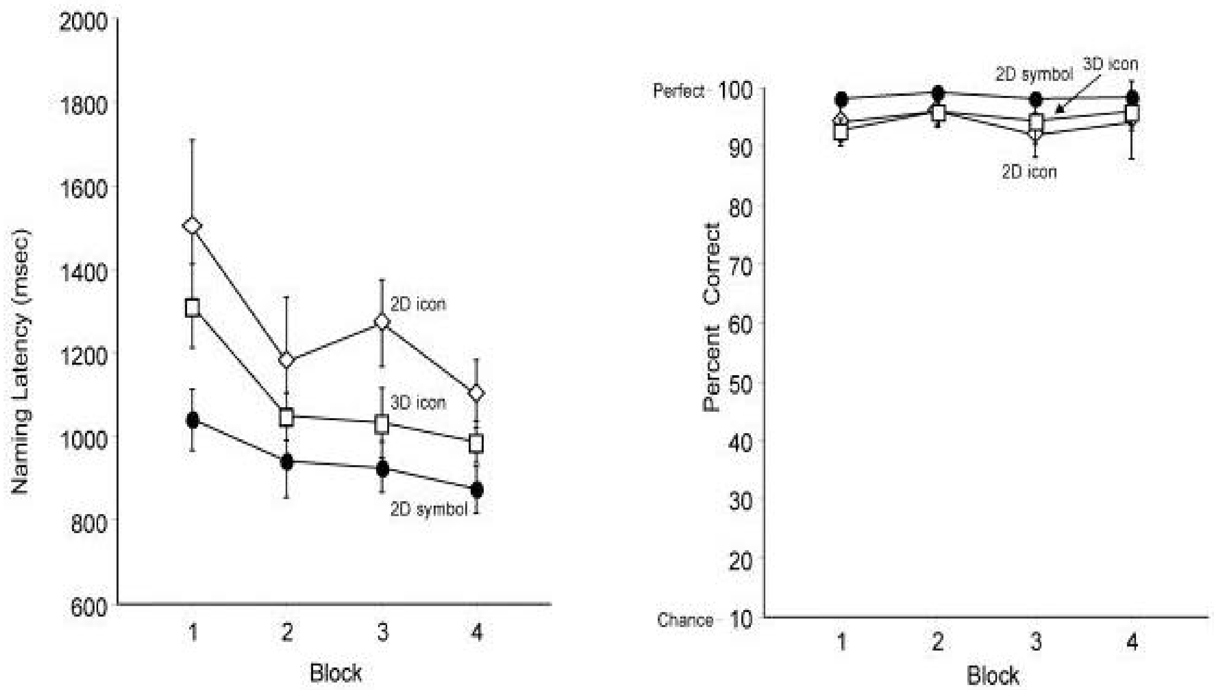

Figure 11. Mean latencies (correct trials only) and accuracy (in percent correct) scores by condition and block for Experiment 3.

When we looked only at symbols with north headings to compare 2-D icons, 3-D icons, and 2-D symbols, we found that there was a main effect of symbol type, $F(2,8) = 12.6$, $p < .01$. Post hoc (Tukey–Kramer) comparisons revealed faster responses on 2-D symbol trials than on 2-D icon trials (by 336 ms, $p < .05$). Thus, icons were slower than 2-D symbols, and it did not matter whether the icons were depicted in 2-D or 3-D.

Letter versus No-Letter Items

Like the first two experiments with novices, when 2-D symbols included a first letter, they were identified faster than the comparable 3-D icons ($F\ (5,20) = 4.9$, $p < .01$). When 2-D symbols did not include a first letter, they were identified only 5 ms faster than the 3-D icons, a non-significant effect.

Expert versus Novice

To analyze the effect of expertise on identification, we conducted a four-way Analysis of the Variance (ANOVA) across Experiments 1 and 3, including expertise as a factor. This anlysis showed a main effect of expertise ($F\ (1,15) = 9.9$, $p < .01$), with experts faster at identification. Of central interest, though, was the interaction of symbol type with expertise, and this was significant ($F\ (1,15) = 6.5$, $p < .05$). There was a smaller performance difference between the 3-D icons and the 2-D symbols for the experts. By the end of the fourth block of trials, the experts were 113 ms faster on the 2-D symbols than the 3-D icons compared to the novices who were 244 ms faster on the 2-D symbols than on the 3-D icons.

Confusions

The experts made fewer confusion errors than the novices did. Expert confusion rate was 3.2%, which was a third of the rate (9.4%) for the novices from Experiment 1. Like the novices, more errors were made with the 3-D icons (5.0%) than the 2-D symbols (1.4%). Confusions were categorized as before, and table 3[3] shows the results.

Table 3. Number of confusions (Experiment 3) by condition for confusions that were made within a platform category and for confusions that were made with platforms sharing the same first letter.

	Confusion Type			
Condition	Platform Category	Not Platform Category	First Letter	Not First Letter
2-D Symbol	(9) 64%	(5) 36%	(6) 43%	(8) 57%
3-D Icon	(49) 98%	(1) 2%	(1) 2%	(49) 98%

The trend evident for the novices from Experiment 1 was amplified with the experts. Nearly all (98%) of the errors made with 3-D icons were platform category errors ($\chi^2 = 42.3$, df = 1, $p < .001$). Also, more first letter errors were made with 2-D symbols than for 3-D icons ($\chi^2 = 28.1$, $df = 1$, $p < .001$).

DISCUSSION

We had wondered whether naval experience might lead experts to identify the 3-D icons faster than the 2-D symbols because the experts would have learned the subtle visual features needed to discriminate between similar platforms. The results were consistent with the findings from Experiments 1 and 2 although there was less statistical power than in the first two experiments (i.e., only five participants). The experts were faster on the 2-D symbols than the 3-D icons. The experts were faster than the novices were. By the last block of trials, the superiority of 2-D symbols over 3-D icons was numerically smaller for the experts than for the novices (113 ms versus 244 ms). Expertise made up for some of the errors found for 3-D icons, but three-dimensional icons were still not identified as well as the 2-D symbols. The experts' overall speed advantage is impressive when one considers that they were 20 years older, on average, than the novices. Generally, we slow as we age, and this is especially true for the time needed to name an object (Feyereisen, 1997).

[3] Yates' (1934) correction for continuity for a small 2 x 2 data table was used in the χ^2 test.

EXPERIMENT 4

In the first three experiments, participants confused platform icons within the same platform category (i.e., ships were confused with ships and planes for other planes). This pattern of errors may reveal a benefit of 3-D icons that was not evident in the identification task. It might be easier to categorize platforms into general classes (ships and aircraft) with 3-D icons than 2-D symbols. Icons convey category information by their gross shape while for symbols participants must first identify and then categorize. Visually similar pictures are categorized faster than they are identified (Snodgrass and McCullough, 1986; Price and Humphrey, 1989). In visual processing, gross shape is also processed before detail (Watt, 1987). In Experiment 4, we tested the hypothesis that 3-D icons are classified faster than 2-D symbols.

METHOD

Participants

Ten college-educated, non-military personnel were recruited from a local software and engineering company and were paid for their participation. Their average age was 33.2 years. Five served in the 'frame-present' condition and five served in the 'no frame' condition.

Design

The 2-D symbols used in the first three experiments slightly complicated matters because the frame surrounding Military Standard 2525 symbols indicates platform category (figure 4). Participants might pick up that a horseshoe-shaped frame was diagnostic of an air track while a square frame was associated with a surface track. The classification task could be solved by simple detection of a visual feature. To prevent this, we had two conditions, one in which the 2-D symbols included frames and one in which the frames were removed from the symbols. The second condition required symbol identification for classification. If the hypothesis were correct, then 3-D icons would be classified faster in the second condition.

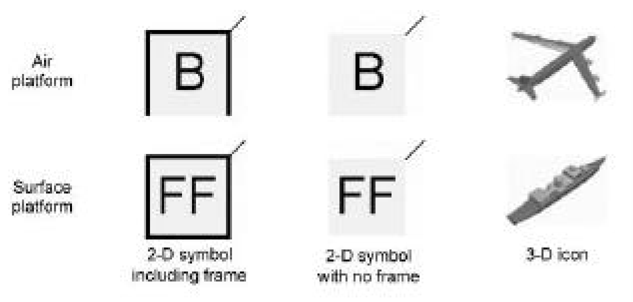

Figure 12. Examples of the three types of symbols that participants were asked to classify into air or surface platforms in Experiment 4. Top, example of an air platform (bomber) shown as a 2-D symbol with a frame (left), a 2-D symbol without a frame (center), and as a 3-D icon (right). Bottom, example of a surface platform, a frigate, shown for same three symbol types.

Materials

The stimuli in the ‘frame-present’ condition were the same as the 2-D symbols and 3-D icons used in Experiment 1. In the ‘no-frame’ condition, we stripped the outside frame from the symbols. Figure 12 shows examples of stimuli from the two conditions.

Procedure

As before, participants first studied a poster showing the different symbol sets for 5 minutes. In the ‘frame-present’ condition, they were shown that the presence or absence of the bottom line of the symbol frame was diagnostic of platform category. Participants were instructed to categorize the displayed stimulus into a sea or air platform as quickly and as accurately as possible. They were instructed to indicate their choice by hitting one of two labeled keys on the computer keyboard. The computer recorded responses to an accuracy of 1 ms. The correct word ‘sea’ or ‘air’ appeared in the middle of the screen after each response.

Each participant served in four blocks of 100 trials each. Fifty trials in each block presented 3-D icons (10 platforms times 5 headings) and 50 trials presented 2-D symbols (10 platforms times 5 headings). The trials were presented randomly within a block. The entire procedure was finished in about 20 minutes, with the participants taking a short break between each block.

RESULTS

Figure 13 shows mean latencies (correct trials) for the two conditions. Performance increased across blocks (F (3,24) = 66.5, $p < .0001$), with performance increasing faster for the 2-D symbols than for the 3-D icons (F (3,24) = 7.6, $p < .001$). Post hoc comparisons revealed that the only significant difference between the symbol conditions occurred in the first block when the 2-D symbols with frames were slower than the 3-D icons ($p < .05$). Thus, by the second block, there was no 3-D icon benefit for platform categorization even over 2-D symbols without frames. Accuracy averaged 98.3% correct with no significant differences across conditions.

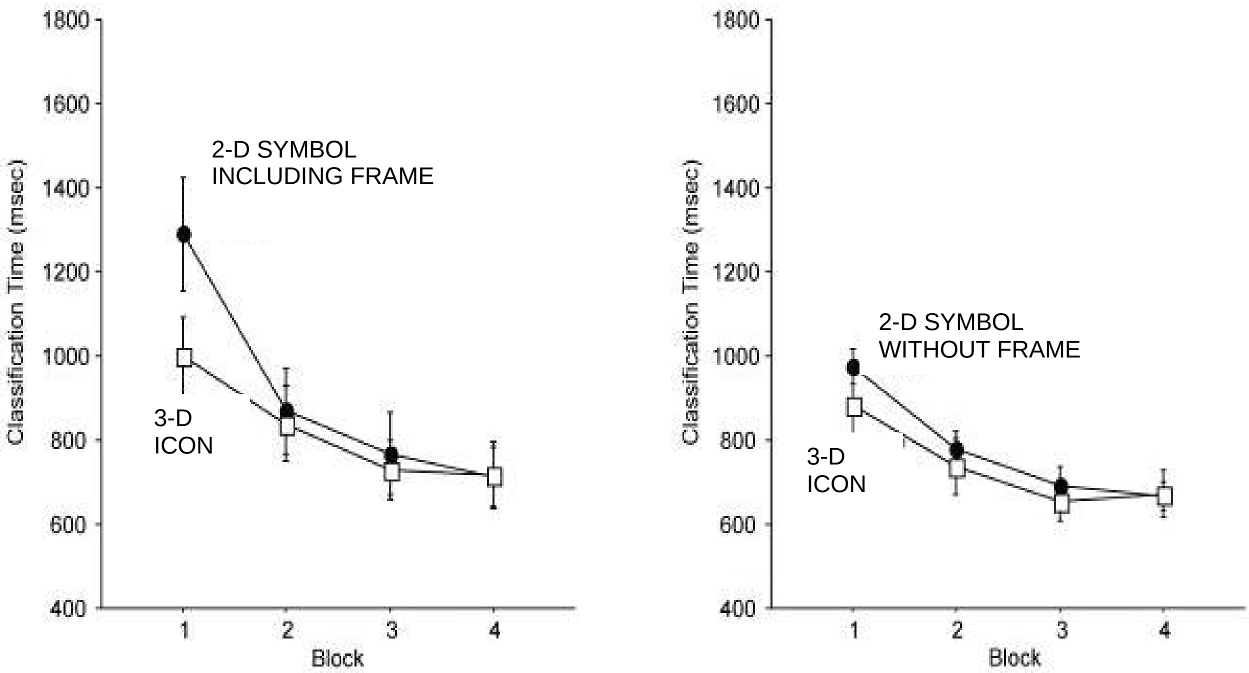

Figure 13. Mean latencies (correct trials only) by condition and block for Experiment 4. Left, mean latencies for 2-D symbols with frames and 3-D icons. Right, latencies for 2-D symbols without frames and 3-D icons.

DISCUSSION

After the first block of trials, 3-D icons showed no platform classification benefit over 2-D symbols, with or without frames. This is surprising because the shape of icons should convey category information more efficiently than abstract symbols, which must first be identified and then categorized. Our findings suggest that even for general classification tasks, there is no great advantage for 3-D icons.

GENERAL DISCUSSION

Performance for conventional 2-D symbols was consistently better than for 3-D realistic icons. The poor identification performance with the icons raises several questions. Was there something in our task or our choice of visual stimuli that penalized our 3-D icons unfairly? Are icons inherently inferior to symbols for use on tactical displays, and if so, why? How might our thinking about recognition of icons versus symbols be informed by theoretical work on object recognition by human beings?

Did our choice of visual stimuli influence our results? We asked participants to identify or classify symbols from a small set of icons or symbols of different platforms. We chose this mix of platforms by what might be encountered on a typical naval tactical display. Such a display would likely depict the environment around a carrier battle group that would include a carrier, frigates, fighters, and helicopters. At 4.7 degrees of visual angle across, we displayed the 3-D icons at a bigger size than they would be shown on a typical tactical display. We did this to maximize the perception of 3-D icon shape. In most 3-D perspective displays such as the AADC prototype, distant track symbols are scaled down. At far distances, the icons will become difficult to identify because one cannot discern the small features that distinguish them. We minimized this problem by showing large images of the icons.

We defined performance as the time required to produce the correct name of a depicted platform. We found that the letter code used in the symbol set was effective at eliciting rapid, accurate identification. However, even those 2-D symbols that did not possess a letter were named about 100 ms, or 10% faster than the 3-D icons in Experiments 1 and 2. This suggests that 3-D icons may not be an effective memory aid for cluttered tactical displays.

By their nature, icons are as easy or difficult to discriminate as the visual images of the objects they represent. All ships are, at a coarse scale of analysis, similar. Ships are elongated floating structures that are functionally different and primarily named through subtly different superstructure configurations. These differences, which are needed for discrimination, exist at a fine spatial scale and, therefore, require some scrutiny. We found that participants confused ships for ships and planes for planes more readily with the 3-D icons. However, 2-D symbols for visually similar platforms can be created as distinct symbols. The Military Standard 2525 set proved effective in this way. Experts, who had never seen this new set before, were 98.5% accurate at identifying the symbols after just 5 minutes of inspection.

Icons were not classified into a general platform category any faster than symbols. This result was surprising because symbols can only be classified after they are identified (which takes time). Icons could be classified by gross shape alone. This finding is inconsistent with the results of other studies that have shown that visually similar pictures are usually classified more quickly than they are identified (Snodgrass and McCullough, 1986).

Moreover, we found that performance with 3-D icons varied significantly with heading in the first experiment. Participants took approximately 10% longer to identify icons with the south headings than with the others. This finding is congruent with that of other studies that have consistently shown that inverted pictures take longer to name (e.g., Jolicoeur, 1985). This was not an issue for the symbols because they were always displayed at the same rotation. Although a 10% increase identification time for the 3-D icons might appear as a relatively inconsequential drop in performance, it is important to consider that we chose viewpoints of the 3-D icons to make them as easy as possible to identify. In realistic operational settings, more unfortunate viewing angles (such as head-on or from directly behind) might arise that would lead to a greater than 10% performance decrement.

What do current theories of recognition say about the relative ease of identification of 3-D icons versus 2-D symbols? The flexibility and accuracy of object recognition by human beings viewing objects under diverse conditions is seen as the pinnacle of our visual performance. Early theoreticians, impressed by the size-invariance of recognition, thought that human beings possessed full 3-D models of the world (Marr and Nishihara, 1978; Biederman, 1987). According to this thinking, 3-D icons, by portraying their real-world shape so well, would have been easier to recognize than 2-D symbols. However, recent perceptual work has started to overturn this earlier theoretical framework. The important observation was that object recognition can display marked viewpoint-dependent effects (e.g., Tarr, Williams, Hayward, and Gauthier, 1998). If our internal model of the world were truly 3-D, then there would be no clear reason why certain viewpoints would be preferable to others. Further, influential experiments in the early 1990s with novel computer-generated objects have shown that recognition performance generalizes better for views of objects that lie between two training views than those that lie outside those views (Bulthoff and Edelman, 1992). This fact is inconsistent with the idea that we have a 3-D model of recognized objects in our brains. Instead, it suggests that we store recognized objects as a collection of 2-D views of what we have viewed earlier. The 2-D view-memorization theory explains these findings. Our results were in line with this recent theory. Our 3-D icons were less identifiable than 2-D symbols.

Because similar platforms have similar iconic views, it is difficult for users to match a rotation of a specific 3-D icon to the correct trace in our memory. Implications of this limitation suggest that 3-D realistic icons put all the work of discriminating between subtly different platforms on the user, which takes time. Discriminating between realistic icons makes life unnecessarily difficult for the user because the icons are difficult to distinguish. We know that discriminability among tactical symbols is a strong predictor of performance in operational tasks (Geiselman and Christen, 1982; Remington and Williams, 1986).

The implications of our findings may be questioned because realistic icons are popular with computer users. At the completion of the second experiment, we asked the participants (from local colleges) about their preferences for the 3-D icons versus the 2-D symbols. Sixty-seven percent said that they would prefer to look at a display populated with 3-D icons. Moreover, a majority, 58% of the participants, believed that they would identify our icons faster than our symbols. These intuitions were inconsistent with our results. As others have noted, users do not always want what is best for them (Andre and Wickens, 1995; Bailey, 1993).

Our results suggest that realistic icon recognition is poor because it is difficult for users to discriminate among the subtle visual differences of military platforms. In contrast, military symbols have been engineered to be distinctive for similar-looking, real-world objects. Symbols can clue users with the first letter of the platform or a visually discriminable analogical indicator such as using cartoon rotor blades. Pre-processing the display in this way might be less popular with users, but it results in faster, more accurate, platform identification. Users might want a familiar realistic representation of military platforms on their display, but they perform better with a distinctive and sometimes unrealistic depiction of it. We recommend using symbols over icons. If the design of the display system requires icons, adding the first letter of the platform name to the icon should make rapid and accurate identification easier.

SUMMARY

In four experiments, we presented participants 10 common military platforms displayed as 3-D icons, 2-D icons, or conventional 2-D symbols (Military Standard 2525). We found that:

- Symbols were identified faster than icons.
- Symbols were identified more accurately than icons.
- Symbols were identified better than icons even when the participants were experts.
- Platform identification improves when the symbol includes the first letter of the platform unless there is more than one platform with the same first letter.
- 3-D icon identification accuracy varies with heading; this is not true for 2-D symbols.
- 3-D icons are confused more often with platforms of the same category.
- 2-D icons and 3-D icons were equally effective for platform identification.
- 2-D symbols and 3-D icons were equally effective for categorization into general classes of platforms (e.g., ships, aircraft).

RECOMMENDATIONS

Based on the results of these experiments, we recommend,

- Use of 2-D symbols rather than 3-D realistic icons in tactical displays when rapid, accurate identification is required.
- Consider using 2-D icons rather than more computationally expensive 3-D icons, if realistic symbology is required.
- If realistic symbology is required, consider adding the first letter of the platform to the icon.

REFERENCES

Andre, A. D. and C. D. Wickens. 1995. "When Users Want What's NOT Best for Them," *Ergonomics in Design*, pp. 10–14.

Bailey, R. W. 1993. "Performance vs. Preference." Human Factors Society 37th Annual Meeting. 11–15 October, Seattle, WA.

Baumann, J. D., S. I. Blanksteen, and M. Dennehy. 1997. "Recognition of Descending Aircraft in a Perspective Naval Combat Display," *The Journal of Virtual Environments*.

Available at http://www.hitl.washington.edu/scivw/JOVE/Articles/mdjbsb.html

Biederman, I. 1987. "Recognition-by-Components: A Theory of Human Image Understanding." *Psychological Review*, vol. 94, no. 2, pp. 115–147.

Bulthoff, H. H. and S. Edelman. 1992. "Psychophysical Support for a Two-Dimensional View Interpolation Theory of Object Recognition." *Proceedings of the National Academy of Sciences, USA*, vol. 89, pp. 60–64.

Christ, R. E. and G. M. Corso. 1983. "The Effects of Extended Practice on the Evaluation of Visual Display Codes," *Human Factors,* vol. 25, pp. 71–84.

Dennehy, M. T., D. W. Nesbitt, and R. A. Sumey. 1994. "Real-Time Three-Dimensional Graphics Display for Antiair Warfare Command and Control." *Johns Hopkins APL Technical Report,* vol. 15, no. 2, pp. 110–119.

Ferrand, L., J. Segui, and J. Grainger. 1996. "Masked Priming of Word and Picture Naming: The Role of Syllabic Units," *Journal of Memory and Language,* vol. 35, pp. 708–723.

Feyereisen, P. 1997. "A Meta-Analytic Procedure Shows an Age-Related Decline in Picture Naming: Comments on Goulet, Ska, and Kahn (1994)," *Journal of Speech and Hearing Research,* vol. 40, no. 6, pp. 1328–1333.

Florence, D. and R. E. Geiselman. 1986. "Human Performance Evaluation of Alternative Graphic Display Symbologies," *Perceptual and Motor Skills,* vol. 63, pp. 399–406.

Geiselman, R. E. and F. G. Christen. 1982. "Perceptual Discriminability as a Basis for Selecting Graphic Symbols," *Human Factors,* vol. 24, pp. 329–337.

Harwerth, R. S. and D. M. Levi. 1978. "Reaction Time as a Measure of Suprathreshold Grating Detection," *Vision Research,* vol. 18, pp. 1579–1586.

Hayward, W. G. 1998. "Effects of Outline Shape in Object Recognition," *Journal of Experimental Psychology: Human Perception and Performance,* vol. 24, pp. 427–440.

Jolicoeur, P. 1985. "The Time to Name Disoriented Natural Objects," *Memory and Cognition,* vol. 13, 289–303.

Jolicoeur, P. and K. G. Humphrey. 1998. "Perception of Rotated Two-Dimensional and Three-Dimensional Objects and Visual Shapes." *In Perceptual Constancies: Why Things Look as They Do,* pp. 69–123, V. Walsh and J. J. Kulikowski, Ed. University Press, New York, NY.

Liter, J. C. and H. H. Bulthoff. 1998. "An Introduction to Object Recognition," *Zeitschrift fur Naturforschung C-A Journal of Biosciences*, vol. 53c, pp. 610–621.

Liter, J. C., B. S. Tjan, H. H. Bulthoff, and N. Kohnen. 1997. "Viewpoint Effects in Naming Silhouette and Shaded Images of Familiar Objects." Technical Report No.54. Tubingen, Germany: Max-Planck-Institut fur Biologische Kybernetik.

Marr, D. and H. K. Nishihara. 1978. "Representation and Recognition of the Spatial Organization of Three-Dimensional Shapes." *Proceedings of the Royal Society of London B*, vol. 200, pp. 269–294.

Mil-Standard-2525B. *Common Warfare Symbology*, 15 December 1996.

NATO Naval Armaments Group IEG/5-SG/8 Ninth Meeting. 1989. "An Evaluation of Three Tactical Symbol Set Options: Working Paper Three Evaluation." TNO Institute for Perception. 26–30 June, Soesterberg, Netherlands.

Oldfield, R. C. and A. Wingfield. 1965. "Response Latencies in Naming Objects," *Quarterly Journal of Experimental Psychology*, vol. 17, 273–281.

Palmer, S. E., E. Rosch, and P. Chase. 1981. "Canonical Perspective and the Perception of Objects," In *Attention and Performance* vol. IX, pp. 135–151, J. Long and A. Baddeley, Eds. Lawrence Erlbaum Associates, Hillsdale, NJ.

Price, C. J. and G. W. Humphrey. 1989. "The Effects of Surface Detail on Object Categorization and Naming," *Quarterly Journal of Experimental Psychology*, vol. 41A, 797–828.

Remington, R. and D. Williams. 1986. "On the Selection and Evaluation of Visual Display Symbology: Factors Influencing Search and Identification Times," *Human Factors*, vol. 28, pp. 407–420.

Richards, W., J. J. Koenderink, and D. D. Hoffman. 1987. "Inferring 3-D Shape from 2-D Silhouettes," *Journal of the Optical Society of America*, vol. 4, pp. 1168–1175.

Schiller, N. O. 1998. "The Effect of Visually Masked Syllable Primes on the Naming Latencies of Words and Pictures," *Journal of Memory and Language*, vol. 39, 484–507.

Smallman, H. S., E. Schiller, and C. A. Mitchell. 1999. "Designing a Display for the Area Air Defense Commander that Promotes Rapid Situation Awareness: The Role of 3-D Perspective Views and Realistic Track Symbols." SSC San Diego Technical Report 1803. SSC San Diego, CA.

Snodgrass, J. G. and B. McCullough. 1986. "The Role of Visual Similarity in Picture Categorization," *Journal of Experimental Psychology: Learning, Memory and Cognition*, vol. 12, pp. 147–154.

St. John, M. and M. Cowen. 1999. "Use of Perspective View Displays for Operational Tasks." Technical Report 1795. SSC San Diego, CA.

Tarr, M. J., P. Williams, W. G. Hayward, and I. Gauthier. 1998. "Three-Dimensional Object Recognition is Viewpoint Dependent," *Nature Neuroscience*, vol. 1, pp. 275–277.

Watt, R. J. 1987. "Scanning from Coarse to Fine Spatial Scales in the Human Visual System After the Onset of a Stimulus," *Journal of the Optical Society of America* vol. A, no. 4, pp. 2006–2021.

Wickens, C. D., S. Todd, and K. Seidler. 1989. *Three-Dimensional Displays: Perception, Implementation and Applications* (ARL-89-11/CSERIAC-89-1). University of Illinois Institute of Aviation Technical Report. University of Illinois, Savoy, IL.

Yates, F. 1934. "Contingency Tables Involving Small Numbers and the Chi Square Test," *Royal Statistical Society (Series B),* vol. 1, pp. 217–235.

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13. ABSTRACT *(Maximum 200 words)*

Conventional tactical display depict military assets using non-realistic two-dimensional (2-D) symbols. Prototypes of three-dimensional (3-D) tactical displays are under development that depict assets using miniature realistic icons. This report discusses four experiments that tested the performance benefits of these icons.

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Mission Area: Command, Control, Communications, Computers, and Intelligence

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